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Colour in Illuminating Engineering*

By W. D. WRIGHT, A.R.C.S., D.Sc. *(Member)*.†

Synopsis

The paper reviews some of the problems of colour perception as they affect the illuminating engineer. Reference is made to the processes of colour perception, and to the relation between the colour of an object and the spectral composition of the light which it reflects. Colour matching by a mixture of three matching stimuli is described, together with the development of the C.I.E. system of colour specification. An elementary discussion of the maximum amount of light which a coloured surface can reflect is given, and the representation of the colour of a surface with the aid of a colour chart, in particular the charts based on the Munsell and Ostwald systems, is referred to. Finally, the dependence of the colour-rendering properties of an illuminant on the spectral composition of the illumination is stressed, and mention is made of the extent to which changes in the quality of the illumination may be compensated by changes in the colour adaptation of the eye.

Introduction

It is no new thing for the illuminating engineer to express an interest in colour, since one of the reasons why we need light is to see colour. Nevertheless, interest in colour has been very considerably heightened in recent years and the subject has assumed a technical importance which it certainly did not possess even ten years ago. This may, in part, be attributed to the introduction of the fluorescent lamp, yet the extended use of colour for improving visibility, for its decorative effect, for signalling purposes, for advertising, and in other ways, would no doubt have gone ahead without the added stimulus of the fluorescent lamp. At the same time, this lamp has created its own special problems which have made the subject more interesting to the scientist and more troublesome to the engineer, and has, indeed, introduced a sense of urgency into certain colorimetric matters.

It is not easy to set any limit to the amount of information about colour which the illuminating engineer should possess, for an adequate answer to the simplest question may sometimes involve a deep understanding of the physics, physiology and psychology of vision. It will be useful, therefore, in this paper to review first the processes involved in the perception of colour.

The Nature of Colour Perception

The main factor which determines the colour of a non-luminous object is the spectral composition of the light reflected by it. This, of course, is governed partly by the quality of the incident light and partly by the reflection properties of the surface, the latter being itself a function of the chemical nature of the material, and of the physical structure of the particles or fibres of which the surface is composed. Spectral reflection curves for typical coloured surfaces are illustrated in Fig. 1.

Spectral hues range in continuous gradation from red through orange to yellow, yellow-green and green, and then through blue-green to blue and violet. The non-spectral hue of purple is observed when the red and blue ends of the

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† Assistant Professor in Colour Vision at the Imperial College of Science and Technology, London.

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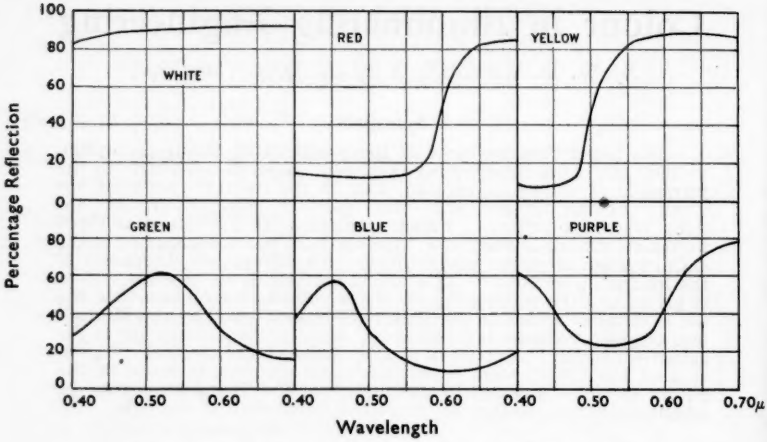

Fig. 1. Typical spectral reflection curves for coloured surfaces.

spectrum are mixed. In the case of a coloured surface which reflects broad bands of the spectrum, it is reasonable to suppose that the hue of the surface, when illuminated by white light, is determined by that band of the spectrum which predominates in the reflected light. This is in fact broadly true, as demonstrated by the curves in Fig. 1, but in detail is inaccurate, since account has to be taken of the additive mixture of *all* the radiations reflected from the surface. The fact that the spectral components of a beam of light are mixed *additively* as they enter the eye is a fundamental aspect which needs to be stressed and which makes the proper understanding of the facts of colour mixture so important.

Thus, a beam of light which enters the eye consists, except in most unusual circumstances, of a number of radiations of various frequencies through the spectrum. These radiations illuminate the retina as a mixed beam and react in the receptors simultaneously. They can therefore be regarded as an additive mixture of rays with as much justification as two or more separate beams which are combined by some optical device or other.

These facts will be discussed later; for the present it will be sufficient to consider what happens to the light when it strikes the retina. Precise knowledge of the visual processes is still lacking, but it seems certain that the first reaction is a photo-chemical decomposition occurring within the millions of light-sensitive receptors in the retina. In some way not fully understood, the products of the photo-chemical reaction give rise to nerve impulses which are transmitted across the neurone layers in the retina to the nerve fibres composing the optic nerve, and thence to the brain.

The ability to discriminate different hues throughout the spectrum necessarily implies that the quality of the visual response in the retina must vary with the wavelength of the stimulus. Colour matching experiments strongly support the view that among the cone receptors, which are generally believed to be the receptors through which colour vision is mediated, there must be three types of receptor which are respectively sensitive maximally in the red, green and blue regions of the spectrum. If this is so (and Granit's recent work by electro-physiological methods (1) gives valuable, direct physiological evidence

in support of the theory), then as the wavelength of the light entering the eye is changed, so the relative activities among the three types of receptor would vary and an adequate mechanism to account for the discrimination of spectral hues would have been derived.

Although future research will no doubt reveal many complexities in the process, this broad conception of three receptor processes and three types of response is certainly adequate at the present time for any discussion of colour as applied to illuminating engineering. In addition, however, it must be remembered that colour responses are affected by those changes in sensitivity which are normally associated with adaptation and contrast, so that neither the intensity nor the quality of the visual response is predetermined by the intensity and spectral composition of the light entering the eye. While the response is primarily determined by the stimulus, it is subject also to modification according to the sensitivity of the retina.

The end-product of the visual process is the visual sensation. It is generally stated that there are six primary colour sensations, namely, red, yellow, green, blue, black and white, and surface colours at least can be qualitatively described in terms of these six attributes. Thus, brown might be described as containing something of the quality of redness, something of yellowness and something of blackness in its appearance. Alternatively, the quality of a surface may be described in terms of its hue, lightness and saturation, where the hue is the quality which distinguishes red from yellow, green from blue, etc., lightness is the quality which distinguishes a light from a dark surface, and saturation the quality which distinguishes a vivid colour from a pale colour.

These are the qualities in which we are primarily interested and which matter in an artistic design, but as they are subjective attributes, they are not susceptible to quantitative measurement. They are, however, related to certain colorimetric attributes which can be measured, as indicated in the following section.

The Facts of Colour Mixture

The experimental fact underlying colorimetry is the possibility of matching a colour by a suitable mixture of three radiations, which in practice are generally chosen to be saturated red, green and blue stimuli, although this choice is not essential. If the three stimuli, to which we will give the symbols R, G and B, are defined, physical radiations, and if the amounts required to match a colour C are given by u, v and w respectively, then the colour C can be defined by the equation

$$C = u.\,R + v.\,G + w.\,B.$$

A further fundamental observation is the fact that if a colour C_1 is matched according to the equation

$$C_1 = u_1.\,R + v_1.\,G + w_1.\,B$$

and a second colour C_2 according to the equation

$$C_2 = u_2.\,R + v_2.\,G + w_2.\,B$$

then it is found experimentally that an additive mixture of the colours C_1 and C_2 is matched according to the equation

$$C_1 + C_2 = (u_1 + u_2)\,.\,R + (v_1 + v_2)\,.\,G + (w_1 + w_2)\,.\,B.$$

The additivity of these colour equations allows the ordinary processes of arithmetic—addition, subtraction, multiplication and division—to be applied generally; for example, an equation for C in terms of R, G and B can be transformed into an equation in terms of three other stimuli X, Y and Z, provided X, Y and Z are themselves known in terms of R, G and B.

The elaboration of the trichromatic system has been described in detail

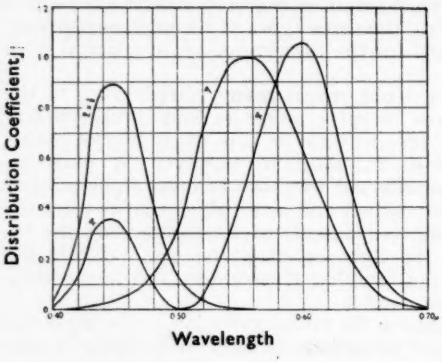

Fig. 2. The equal-energy distribution curves as defined in the C.I.E. system of colour measurement. The $\bar{x}$, $\bar{y}$ and $\bar{z}$ coefficients show the amounts of the red, green and blue stimuli, X, Y and Z respectively, required to match the colours in the spectrum.

elsewhere (2) and there is no occasion to develop the principles on any extensive scale here. It is convenient, however, to describe applications of the system in terms of the framework established in 1931 by the Commission Internationale de l'Eclairage for the standardisation of colour specifications. In this framework the amounts of three defined stimuli X, Y and Z, required by an average observer to match all the colours throughout the equal-energy spectrum, have been tabulated to give what are known as the equal-energy distribution coefficients. The graphical form of the data is shown in Fig. 2, in which the distribution coefficients $\bar{x}$, $\bar{y}$ and $\bar{z}$ are plotted against the wavelength λ to give the equal-energy distribution curves.

These curves were derived from actual colour-matching experimental data and might conveniently (although incorrectly) be regarded as representing the spectral sensitivity curves of the red, green and blue processes assumed to be present in the retina. One set of curves of this type almost certainly does correspond to the sensitivity curves of the three processes, but the set of curves obtained from experimental data depends on the choice of stimuli X, Y and Z. In the C.I.E. system, the stimuli were chosen on the basis of technical convenience and not on account of any physiological significance they might possess; it follows that the resulting distribution curves shown in Fig. 2 cannot be the actual physiological sensitivity curves. In so far, however, as a mental picture assists in their understanding, no great harm is done if the distribution curves are regarded as having the properties of spectral sensitivity curves.

The importance of these curves lies in the fact that, with their aid, it is possible to calculate the amounts x^1, y^1 and z^1 of the stimuli X, Y and Z which are required to match a colour C, when that colour is specified in terms of its spectral composition or spectral energy curve. The method of calculation is similar to that used with the equal-energy luminosity curve to calculate, say, the transmission factor of a filter or the reflection factor of a surface. In that calculation, which is illustrated pictorially in Fig. 3, the energy at each wavelength in the beam of light under test, is weighted by its corresponding luminosity factor and the weighted values added together. In the case of a beam of light passing through a filter, the sum of these weighted values for the incident beam gives a figure which is proportional to the intensity of the incident beam, while the corresponding sum for the transmitted beam gives the intensity of the transmitted light. The ratio of the two sums then gives the transmission factor of the filter.

When the calculation is extended to the three distribution curves of Fig. 2, the summation has to be carried out for each of the three curves, and three values, x^1, y^1 and z^1, are obtained for each beam under investigation. (It should in passing be mentioned that the $\bar{y}$ distribution curve is identical with the

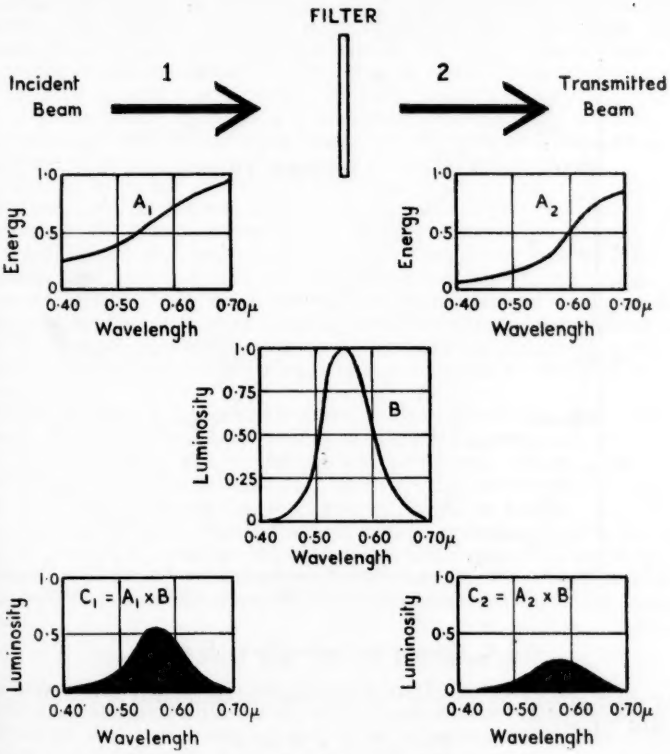

Fig. 3. The calculation of the transmission factor of a filter with the aid of the standard luminosity curve.

A_1 — Spectral energy curve for beam 1 before transmission through filter.

A_2 — Spectral energy curve for beam 2 after transmission through filter.

B — Standard luminosity curve for equal energy spectrum.

C_1 — Energy curve A_1 weighted by luminosity curve B.

C_2 — Energy curve A_2 weighted by luminosity curve B.

Transmission factor of filter = Area under curve C_2 divided by Area under C_1.

equal-energy luminosity curve. The means by which this identity is secured need not be discussed here, but as a consequence the y^1 values can be used to derive the reflection or transmission factor of a sample, etc.) The absolute values of x^1, y^1 and z^1 are governed by the total intensity of the light, but the colour quality of the light is a function of the relative amounts of x^1, y^1 and z^1. It is in many cases convenient to separate these two aspects by dividing x^1, y^1

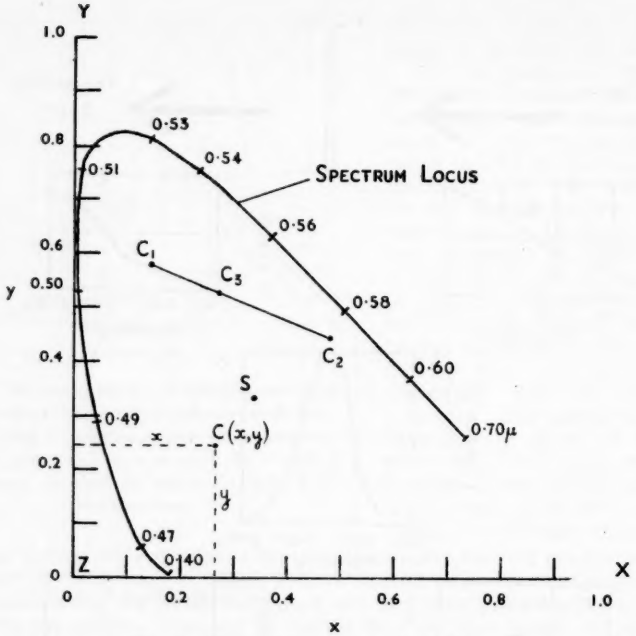

Fig. 4. Chromaticity chart on the C.I.E. system.

and z^1 by their sum $(x^1 + y^1 + z^1)$, so that the colour quality C can be expressed by the unit equation

$$C = x.X + y.Y + z.Z,$$

$$\text{where } x = \frac{x^1}{x^1 + y^1 + z^1}$$

$$y = \frac{y^1}{x^1 + y^1 + z^1}$$

$$z = \frac{z^1}{x^1 + y^1 + z^1}$$

and necessarily $x + y + z = 1$.

The coefficients x, y and z in this unit equation are generally referred to as the trichromatic coefficients for the colour C. When two of these coefficients are known, the third can be found directly, and the colour quality as thus defined becomes a function of two variables only. C can therefore be represented in a plane diagram such as the chromaticity chart of Fig. 4, in which the location of C is determined by its co-ordinates (x and y).

Fig. 4 is in effect a colour chart in which the distribution of colours is based on the results of colour mixture. Thus the particular position of any colour C in the chart arises from the fact that the same quality of colour can be produced by a mixture of the stimuli X, Y and Z taken in the proportions x, y and z respectively. On this chart, red colours are located in the right-hand side of the diagram, yellows roughly mid-way between X and Y, greens towards

the Y corner, blues and violets towards the Z corner, purples between X and Z, and white in the middle. It must be remembered that the chart does not distinguish between a light or dark colour of the same quality, thus a brown and an orange might be represented by the same point. With this limitation, the diagram can be regarded as a colour chart and used in much the same way as a book of patterns for identifying a particular colour. This is in fact one of its important uses, and illuminating engineers are familiar with this application in connection with the specification of the colour of signal glasses.

In addition to its use as a colour atlas, the chart can be used for analytical purposes, and for this purpose it is necessary to show the position of the spectrum colours in the chart. From actual colour-matching experiments, in which each spectral colour was measured in turn by matching it with a mixture of a red, green, and blue stimuli*, the co-ordinates of the spectral colours in the C.I.E. chromaticity chart of Fig. 4 have been derived for the standard observer, and are shown in that diagram by the spectrum locus. From a knowledge of the colours of the different wavelengths in the spectrum, a still clearer picture of the distribution of the colours in the chart can be obtained by studying this locus.

For the purpose of the analysis given in the following section, two further properties of the chromaticity chart should be mentioned. First, if two stimuli, C_1 and C_2 (Fig. 4), are mixed additively, the colour quality of the mixture is represented by the point C_3, where C_3 lies on the straight line joining C_1 and C_2. This is essentially the same problem as finding the centre of gravity of two weights, so that if the radiation C_1 preponderates in the mixture, C_3 will be near to C_1, and so on. Secondly, since white occurs in the centre of the chart, for example at the point S, the nearer a colour is located to S, the whiter it will be, while the closer it lies to the spectrum locus, the more vivid the colour.

The Lightness and Hue of Coloured Surfaces

One general problem of great interest in the colour industries is that of producing dyes and pigments which, when applied to a surface, produce a high light reflection and also a saturated or vivid colouring. Now illuminating engineers are also very much concerned with this problem, since while they must accept the need for coloured decorative schemes because of their aesthetic value, they have to allow for the fact that coloured surfaces reflect less light than white surfaces, and therefore a room with coloured walls, ceilings, and furnishings reflects less light than a room with white ceilings, etc. They must therefore consider what colours reflect the most light and what factors limit the light reflection properties of each hue.

In discussing this question in this section, use is made of an approximate method of analysis which has been described recently elsewhere ([3]), but which, in spite of its obvious inaccuracy, does lead to a fairly simple mental picture of the problem. The reflection factor of a surface is the ratio of the light reflected from the surface to the light incident on it. (It will be convenient at this stage to assume the surface to be perfectly diffusing, so that the difficulties associated with the diffuse and specular components of the reflected light do not arise.) For a given quality of illumination, the spectrum can be divided into ten bands, in which each band contributes ten per cent. of the incident light flux. The boundaries of the bands as calculated for the S_C daylight illuminant (colour temperature 6,500° K) are shown in Fig. 5; they are

*In practice, a spectral stimulus has to be diluted by admixture with one or other of the three matching stimuli before it can be matched by an additive mixture of the red, green, and blue stimuli.

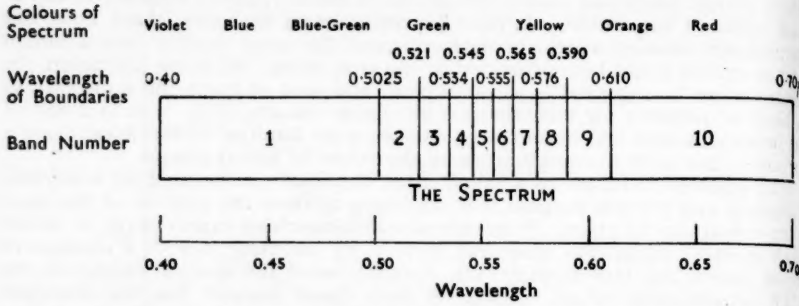

Fig. 5. The spectrum divided into ten bands, each of which contributes ten per cent of the light flux in the daylight illuminant S_C, colour temperature 6,500° K.

naturally a function of both the energy distribution of the illuminant and the luminosity curve of the eye. Thus, a relatively narrow band is required in the middle part of the spectrum to make up a ten per cent. contribution, since these radiations are among the more luminous (see the luminosity curve B in Fig. 3), whereas at the two ends of the spectrum, wide bands are required to provide ten per cent. contributions. [Note: These bands should not be confused with the eight spectral bands adopted by lamp makers in this country to specify the colour rendering properties of fluorescent lamps.]

If, now, the curves in Fig. 1 are examined in conjunction with Fig. 5, it is obvious that yellow surfaces, for example, have a very much higher reflection factor than, say, blue surfaces. This must be so, because yellow pigments tend to reflect highly over an extended range of wavelengths which may include at least six or seven of the ten per cent. bands, whereas blue pigments do not normally have such a high efficiency of reflection in their main reflection band and the band may in any case include only one or two of the ten per cent. bands. This illustrates one use of what we may term the "ten waveband principle"—a means of arriving at a quick, approximate estimate of the reflection factors of differently coloured surfaces.

There is, however, a further use. The small reflection of light by blue surfaces, blue-greens, and purples, is only in part due to a somewhat low efficiency of pigments and dyes of these hues. That is one factor, but there is also a theoretical limit to the reflection for a given saturation or vividness of colour, and this limit is a function of the eye. Similarly, the high reflection of saturated yellow, orange, and red surfaces is partly due to the high efficiency of the pigments and partly due to the eye.

Thus, if we take the spectrum locus in the chromaticity chart, we can mark round the locus the boundaries of the ten per cent. bands as derived for a given illuminant; for example, those for the S_C illuminant are shown in Fig. 6. Eight of these bands lie on the almost straight portion of the locus along the XY side of the chart, while only two of the bands lie on the more curved section of the locus along the YZ side of the chart. Bearing in mind the "centre of gravity" principle by which the chromaticity of a mixed radiation can be calculated from the chromaticities of the component radiations, it is easy to see that if any or all of the bands three to ten are mixed together, a stimulus is produced which, because of the straightness of the locus, must be located very near the spectrum locus itself, and is therefore highly saturated as well as being highly reflecting. Hence the possibility of bright yellow surfaces.

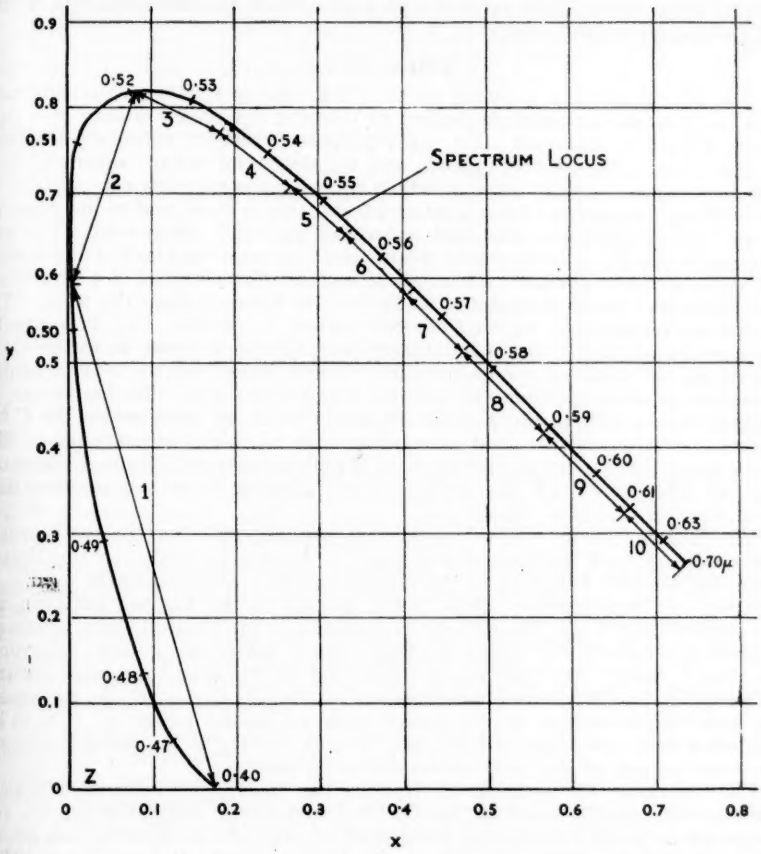

Fig. 6. The spectrum locus in the C.I.E. chromaticity chart showing the boundaries of the bands of Figure 5 for the illuminant S_C.

If bands one and two are mixed together, they produce a fairly saturated blue or blue-green radiation, but the maximum reflection with these two bands alone can, at the most, only be twenty per cent. Any attempt to increase the reflection by including more bands only results in pulling the centre of gravity of the mixed radiation away from the spectrum locus towards the centre of the chart. Hence, highly reflecting blue surfaces can only be secured at the expense of the vividness of the colouring.

For each hue there is, in fact, a maximum reflection for any given saturation or purity of the pattern. These limits have been worked out by MacAdam (4), and have also been located on the Munsell colour system (5). While illuminating engineers need not, perhaps, delve too deeply into these theoretical aspects, they may find it of value to have a general understanding of the

relation between the light reflection of a pattern on the one hand and its hue and saturation on the other.

Colour Charts

The specification of a colour on the C.I.E. system by its unit trichromatic equation provides an absolute method of defining the colour quality of a light source, a filter, or a surface. For many purposes, however, especially in choosing colours for decorative purposes and for designing colour schemes, it is necessary to use a colour atlas in which the coloured patterns can actually be seen. Many atlases have been produced from time to time, and in the majority of cases the patterns are visualised as forming part of a colour solid. The axis of the solid usually corresponds to the neutral colours, with black at the bottom and white at the top; each vertical plane includes the patterns of a given hue, while the more vivid the colour the farther its distance from the axis. The spacing of the patterns varies from one system to another, but is normally based on the subjective characteristics of the patterns and not, as in the C.I.E. system, on the laws of colour mixture. While, therefore, the charts cannot be used to analyse problems of spectral composition and reflection factor, as in the previous section, the patterns themselves can be specified on the C.I.E. system, and hence can be used as sub-standards of colour measurement. The charts, moreover, are frequently used for studying problems of colour harmony, a use for which the C.I.E. system is not well adapted, so that in practice they are of very great value indeed.

The British Colour Council charts are probably familiar to most people in this country, and they are widely used in decorative work. In the United States the Munsell system and the Ostwald system are frequently used. A great deal of experimental work on the spacing of the Munsell patterns has been carried out ([6]), and the patterns as provided by the Munsell Color Company are used extensively for colour grading, colour matching, colour designing, and so on. About 1,000 patterns are provided in this atlas, and each pattern can be given its trichromatic specification on the C.I.E. system, as calculated from spectro-photometric measurements made on master patterns. It is to be hoped that more advantage will be taken in this country of the Munsell system, where the nature of the problem warrants its use.

The Container Corporation of America has recently introduced a Colour Harmony Manual ([7]) based on the Ostwald system, in which the colours are reproduced on a cellulose acetate base, matt on one side of the chip and glossy on the other. In this atlas the colour solid is divided into 24 hues and includes 680 patterns in all. These patterns are also specified on the C.I.E. system, and the atlas seems destined to play an important role in technical and design work on colour.

Which atlas is used depends very largely on the nature of the problem in hand. For the illuminating engineer, the important thing is to know what charts exist and to make his choice accordingly.

Colour Rendering Properties of Illuminants and Colour Constancy

From the point of view of both the illuminating engineer and the user of illumination, the colour of the light from a source is generally of less importance than its colour rendering properties. It is important to realise that two light sources having entirely different spectral energy distributions may appear identical to the eye so far as their colour is concerned. Thus, one white light source may radiate energy through the whole of the visible spectrum, while another source may have a discontinuous spectrum with only a few

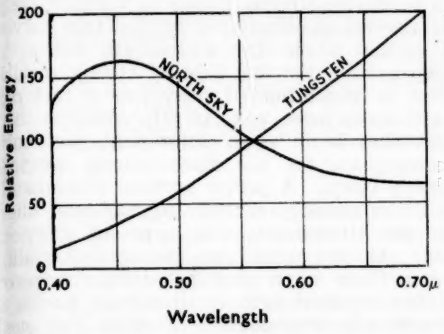

Fig. 7. Spectral energy curves for light radiated by a typical tungsten lamp and by the north sky.

bright lines at isolated points in the spectrum and yet also appear white. The colour rendering properties of the two sources would be very different, since the light reflected from a surface depends on the spectral composition of the illuminant and not merely on its colour. Again, a yellow illuminant obtained by using a tungsten lamp with a yellow filter may look similar in colour to the sodium lamp, but coloured surfaces examined under the two radiations would differ very strikingly, since the former includes a continuous range of wavelengths from the red to the green, while the latter consists of two very bright lines in the yellow part of the spectrum.

For many purposes, we are not concerned with such violent examples as this, but we are very frequently concerned with the effect of changes in the quality of illumination such as occur between the yellowish light of the tungsten lamp and the bluish light of daylight.

Certain colours change very strikingly in appearance when transferred from daylight to tungsten light, but these are exceptional and arise most often because of high reflection values at the two extremes of the spectrum. In many other cases, however, we are not normally conscious of great changes in colour quality; for example, the average furnishings in a room do not usually look very different when seen by the daylight from the window or by the light from tungsten lamps at night.

The eye does, in fact, tend to allow for changes in the quality of the illumination by a process of adaptation and adjustment. If there are excess red radiations in the illumination, then the stimulation of the retina by such a spectral composition produces excess activity in the red receptor process, which in turn reduces the sensitivity to the red radiations and tends to compensate for the abnormal quality of the light. The analysis of colour adaptation phenomena is, however, highly complicated and not fully understood, and it does not in any case seem legitimate to regard the retina as made up of three entirely independent colour response processes which adapt independently of each other ([8]). In the present state of our knowledge we can only postulate a general tendency to compensate for excess radiations in one part of the spectrum or in another.

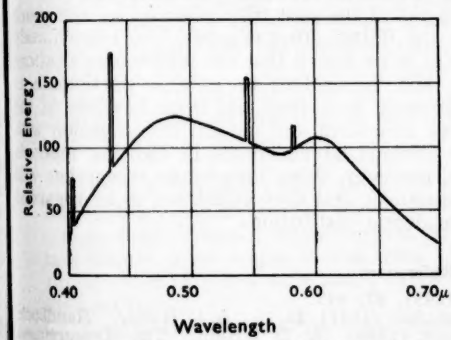

Fig. 8. Spectral energy curve for the light radiated by a typical fluorescent "daylight" lamp.

The change from daylight to

relation between the light reflection of a pattern on the one hand and its hue and saturation on the other.

Colour Charts

The specification of a colour on the C.I.E. system by its unit trichromatic equation provides an absolute method of defining the colour quality of a light source, a filter, or a surface. For many purposes, however, especially in choosing colours for decorative purposes and for designing colour schemes, it is necessary to use a colour atlas in which the coloured patterns can actually be seen. Many atlases have been produced from time to time, and in the majority of cases the patterns are visualised as forming part of a colour solid. The axis of the solid usually corresponds to the neutral colours, with black at the bottom and white at the top; each vertical plane includes the patterns of a given hue, while the more vivid the colour the farther its distance from the axis. The spacing of the patterns varies from one system to another, but is normally based on the subjective characteristics of the patterns and not, as in the C.I.E. system, on the laws of colour mixture. While, therefore, the charts cannot be used to analyse problems of spectral composition and reflection factor, as in the previous section, the patterns themselves can be specified on the C.I.E. system, and hence can be used as sub-standards of colour measurement. The charts, moreover, are frequently used for studying problems of colour harmony, a use for which the C.I.E. system is not well adapted, so that in practice they are of very great value indeed.

The British Colour Council charts are probably familiar to most people in this country, and they are widely used in decorative work. In the United States the Munsell system and the Ostwald system are frequently used. A great deal of experimental work on the spacing of the Munsell patterns has been carried out ([6]), and the patterns as provided by the Munsell Color Company are used extensively for colour grading, colour matching, colour designing, and so on. About 1,000 patterns are provided in this atlas, and each pattern can be given its trichromatic specification on the C.I.E. system, as calculated from spectro-photometric measurements made on master patterns. It is to be hoped that more advantage will be taken in this country of the Munsell system, where the nature of the problem warrants its use.

The Container Corporation of America has recently introduced a Colour Harmony Manual ([7]) based on the Ostwald system, in which the colours are reproduced on a cellulose acetate base, matt on one side of the chip and glossy on the other. In this atlas the colour solid is divided into 24 hues and includes 680 patterns in all. These patterns are also specified on the C.I.E. system, and the atlas seems destined to play an important role in technical and design work on colour.

Which atlas is used depends very largely on the nature of the problem in hand. For the illuminating engineer, the important thing is to know what charts exist and to make his choice accordingly.

Colour Rendering Properties of Illuminants and Colour Constancy

From the point of view of both the illuminating engineer and the user of illumination, the colour of the light from a source is generally of less importance than its colour rendering properties. It is important to realise that two light sources having entirely different spectral energy distributions may appear identical to the eye so far as their colour is concerned. Thus, one white light source may radiate energy through the whole of the visible spectrum, while another source may have a discontinuous spectrum with only a few

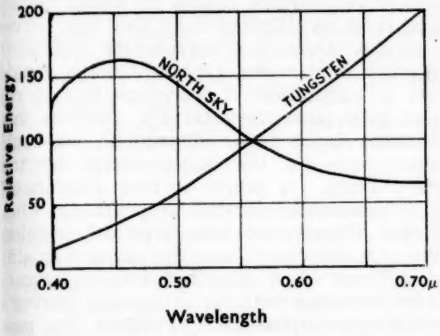

Fig. 7. Spectral energy curves for light radiated by a typical tungsten lamp and by the north sky.

bright lines at isolated points in the spectrum and yet also appear white. The colour rendering properties of the two sources would be very different, since the light reflected from a surface depends on the spectral composition of the illuminant and not merely on its colour. Again, a yellow illuminant obtained by using a tungsten lamp with a yellow filter may look similar in colour to the sodium lamp, but coloured surfaces examined under the two radiations would differ very strikingly, since the former includes a continuous range of wavelengths from the red to the green, while the latter consists of two very bright lines in the yellow part of the spectrum.

For many purposes, we are not concerned with such violent examples as this, but we are very frequently concerned with the effect of changes in the quality of illumination such as occur between the yellowish light of the tungsten lamp and the bluish light of daylight.

Certain colours change very strikingly in appearance when transferred from daylight to tungsten light, but these are exceptional and arise most often because of high reflection values at the two extremes of the spectrum. In many other cases, however, we are not normally conscious of great changes in colour quality; for example, the average furnishings in a room do not usually look very different when seen by the daylight from the window or by the light from tungsten lamps at night.

The eye does, in fact, tend to allow for changes in the quality of the illumination by a process of adaptation and adjustment. If there are excess red radiations in the illumination, then the stimulation of the retina by such a spectral composition produces excess activity in the red receptor process, which in turn reduces the sensitivity to the red radiations and tends to compensate for the abnormal quality of the light. The analysis of colour adaptation phenomena is, however, highly complicated and not fully understood, and it does not in any case seem legitimate to regard the retina as made up of three entirely independent colour response processes which adapt independently of each other ([8]). In the present state of our knowledge we can only postulate a general tendency to compensate for excess radiations in one part of the spectrum or in another.

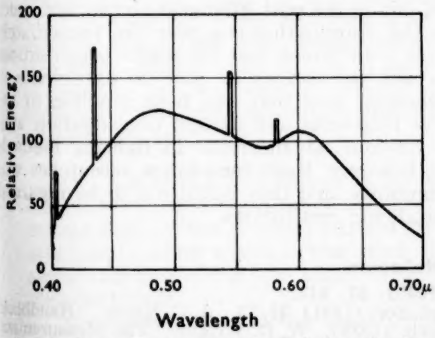

Fig. 8. Spectral energy curve for the light radiated by a typical fluorescent "daylight" lamp.

The change from daylight to

tungsten light can be regarded as a relatively simple change in which merely the balance of red to blue light is altered, as illustrated by the two curves in Fig. 7, which form a kind of see-saw about the wavelength 0.56 μ. It is not difficult to imagine that compensation for this type of change should be fairly complete through a process of adaptation, if there are in fact red and blue receptors in the retina, and experience very largely confirms this. If, on the other hand, we use a mercury lamp as an illuminant, we could not possibly expect the eye to compensate for the discontinuous spectral composition of the light from such a lamp. A white surface illuminated by a mercury lamp may acquire a reasonably whitish appearance when the eye has become adapted to the illuminant; this type of problem has been studied in detail by Judd (9). On the other hand the spectral quality of the light reflected from coloured surfaces when illuminated by a mercury lamp, is so entirely different from that obtained with an illuminant having a continuous spectrum, that compensation is impossible. Perhaps the most familiar example of this is the change in the red colour of a London Transport bus to brown when seen under mercury street-lighting.

The fluorescent lamp provides a very interesting intermediate example in which a line spectrum is superimposed on a more or less continuous spectrum as illustrated in Fig. 8. The eye is not aware of this particular composition and only adapts itself to the overall quality of the light, which we may assume to be reasonably similar to daylight. For many purposes the difference between the spectral composition of true daylight and fluorescent lamp "daylight" is immaterial, but for accurate colour matching in the dyehouse these lamps are hardly to be recommended (10). It is not easy to lay down tolerances in this kind of problem, especially where the non-technical general public are concerned. In some cases the man in the street may be rather critical; as an instance, the difference between the colour of butter and margarine is not very great, and if the lighting in a restaurant is such as to make butter look like margarine, then the restaurant proprietor is not likely to be too pleased. The reverse tendency might be more acceptable!

Conclusion

This paper does little more than raise a corner of the curtain hanging between the illuminating engineer and the science of colour and colour vision. He has in many cases already raised the curtain a long way for himself and studied many of the problems in great detail. An enormous amount of research on colour has been carried out in the past fifty years or so, but much of it has not been in a form which the illuminating engineer can immediately apply to his practical problems. It is to be hoped that the major organisations engaged on lighting developments will themselves be able to participate in colour researches in a more fundamental way than has been possible in the past. Many of the problems require long-term and patient investigation with little expectation of immediate or obvious advancement in lighting methods or lighting equipment. Ultimately, however, these long-range researches will bear fruit of great value to the community, and they ought not to be regarded entirely as the responsibility of academic institutions.

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Discussion

Mr. G. T. WINCH expressed a little disappointment that the written paper had not been expanded to cover a greater field, and suggested that it might be made to cover more completely the subject matter dealt with before it was published in final form.

Referring to the ten-band method described in the paper, he said it was a little unfortunate that it should be ten bands, because the colour-rendering properties of an illuminant were usually judged in relation to eight defined spectral bands, and he hoped there would be no confusion as the result.

The question of colour and its application depended upon the particular use which was to be made of colour measurement and the manipulation of colour, or the understanding of colour would be entirely dependent on the ease with which measurements could be made. In the past, visual colorimetric techniques had tended to be rather laborious, and he looked forward to the future application of developed photoelectric techniques which would enable colour measurements to be made in a few minutes, instead of the very much longer time so often necessary with the older methods. This would make the application of colour knowledge in design much more popular.

It would have been very valuable if the author could have expanded his paper to cover the subjective effects as well as the measurement of the stimulus. We talked of cold and warm sources of light, but he did not think we understood what gave them these characteristics.

Another point it would be interesting to hear more about was the effect of surface texture. This applied not only to walls and decorative surfaces but generally to fabrics, and he believed he was right in saying that dyers made due allowance for the surface texture in dyeing fabrics.

Commenting on the author's plea, at the conclusion of the paper, for more work of this character to be done by the industrial laboratories, he said the author might be glad to know that this was being given very high priority. Indeed, he could speak for all lamp makers when he said they were spending a lot of time and effort in trying to develop methods for the rapid measurement of colour and the understanding of colour and—what was even more important—spectral distribution of light sources. It was common practice now to appraise the efficiency of electric discharge lamps by reference to their luminosity spectral distribution and also their colour appearance in terms of trichromatic coefficients.

Dr. J. H. NELSON, referring to the influence of colour, recalled an instance concerning custard powder which normally contained a small quantity of a certain dye. When a white custard powder was produced it was said by certain people, upon whom it was tried, that it was horrible, but when a microscopic touch of a dye was added to the same custard powder it was said to be the real thing!

Continuing, he said the great trouble at the moment in regard to colour was between the scientific people and the art people. Each thought theirs was the only method of doing things, but he believed he was right in saying

that Dr. Wright was one of the few people who were trying to bring these two sides together, since he did not merely content himself with physical colour measurement, but tried to understand the subject in its broadest terms, thus bringing in both the artist and the maker of lamps.

Mr. W. A. ALLEN said there was one aspect of the colour problem to which the author had not referred, viz., the relationship of black surfaces to colours. He was concerned at the moment with a problem which had some curious aspects, namely, the valuation of hops. It appeared that, for valuing, this well-known material was put up in packages about 6 inch cube. The leaves were dried under controlled conditions, and the appearance was yellow-green mixed with a certain amount of brown, and sometimes with very strong tinges of brown. The hops were compressed, and the packages were open at the end. In valuing showrooms, which had existed for many years, the hops were placed on black benches with a black background to a height of about 3 feet 6 inches. Thus from the waist-line to about eye-level there was a black surface. Above that was a fairly strong green, and above that there was the light source, which was a long roof-light. One was not usually conscious of the light source because the eye was protected by the high angle of elevation to the glazing. He had been somewhat at a loss to analyse the particular effect of the black surface and if there was any supplementary effect from the green surface above. Valuation seemed to be mainly a question of sensitivity to brown in the packets. He asked if the author had any views on this problem.

Mr. J. G. HOLMES said that colour-matchers preferred a bluish white, such as north-sky light, although Dr. Wright had shown that adaptation was fairly complete for any substantially white light with a continuous spectrum. He could understand that a bluish white would be better for distinguishing between two similar yellowish materials because the difference between them would be emphasised. It was a general theorem that differences between similar surface colours were most pronounced under an illumination which had maximum energy at the wave-length of the maximum absorption, and he could not understand why a yellow-rich light should not be used when matching blue materials. The preference for north-sky light did not seem to be dependent on illumination level, and he wondered whether it was due to the fact that a colour-matcher preferred an equi-energy illumination which was equally suitable for all hues and with which he could become familiar, regardless of adaptation.

Illuminating Engineers had progressed through the stages of foot-candles and diversity factors to brightness engineering, and Dr. Wright's paper had given the basic information necessary for colour engineering. We see by contrast of colour as well as by contrast of brightness, and there must be an optimum choice of colour contrast for each visual task, such as black-on-white for reading, blue-on-yellow or black-on-yellow for conspicuous posters and notices, and tones of cream or pale green for background surfaces. Could Dr. Wright comment on this most important aspect of Illuminating Engineering, and could he particularly comment on the relations between colour contrast and acuity and comfort? Was the preference for yellow-rich light in the home, or a yellow chalk board in some schools due to any real advantage in a yellowish background? Did the eyes in fact find difficulty in adaptation to blue-rich light at the lower illumination levels and, if so, how did this affect the colours to be used for visual tasks under artificial light?

Dr. J. W. STRANGE said that on many occasions there had been discussions as to the actual terms used to define light, and particularly the new fluorescent

sources. The author recommended the C.I.E. system, which was of immense value to people working with colour mixtures, but in actual practice even people like himself who had been working on colour problems for many years, had considerable difficulty in visualising colours in terms of X, Y, and Z. That was why, in America particularly, black body colour temperatures are used for the description of the colour of new types of fluorescent lamps. The purist frowns on such a procedure because it implies a similar spectral distribution as well as the same colour, and this is far from the case. The method has, however, the advantage of simplicity and certainly helps greatly in visualising the lamp colour. Its main practical disadvantage is that as the colour becomes "warmer" the black body temperature becomes lower! There was also the method of defining colour in terms of residual colour and degree of saturation. This could be readily linked with the C.I.E. system, and it appealed to him as an accurate method which made it simple to visualise the colour defined. He felt that much greater use could be made of the method.

Mr. J. M. WALDRAM, referring to the point made by Mr. Holmes concerning the best colour of light in which to detect small colour differences, instanced the examination of chromium plated parts for determining whether the plating was complete. The bluish chromium was put on a nickel surface, which was slightly yellow, so that a failure of the chromium plating appeared as a slightly yellow patch. It was desired to use fluorescent lighting for other reasons, and the question was which of the two available colours should be used. As would rather be expected, it was found that the redder "warm white" colour was less satisfactory than the bluer "daylight" colour.

He thought that the use of a black background for examining hops, might touch another phase of the visual process and the problem of local adaptation. If the general background were black the object of regard would be well up on the local adaptation scale, which would help to detect differences in brightness better; and he inquired whether it would also help to distinguish better differences in colour.

He thought that the ten-band colour rendering described by the author gave an elegant explanation of an effect observed in the high pressure mercury lamp, which had in its spectrum a blue line which contributed little to the light, but had a notable effect on the colour. This could very easily be explained by the author's diagram. If there was a slight mist, the blue was scattered preferentially and removed from the direct light; this had a considerable effect on the colour of the light which became so green that it could become confused with a railway signal.

Mr. HOWARD LONG asked if the author had a similar chart for the warm white because frankly he preferred that method of presentation to the eight-band system. It might explain why in certain cases difficulties arose in colour discrimination and therefore such a chart would be of value.

Mr. S. D. LAY referred to a statement by Steinmetz that yellow was an irritant colour, and said that his own experiences tended to confirm this.

He had found that at low values of illumination, much higher ratios of yellow were tolerable than at high illuminations when light containing considerably greater percentages of blue was preferable.

He asked if the author's experience agreed with this, and if so, could he

give any explanation of the reason for this change of colour preference with varying values of illumination?

In view of the tendency to adopt higher illuminations and of the advent of the fluorescent lamp, the matter was of considerable interest at the present time.

Dr. J. N. ALDINGTON said that notwithstanding the refined techniques which were being developed for giving numerical values to both the appearance and colour rendering properties of light sources, it was still essential to go back to the subjective facts. To assess the colour rendering properties of a source it was necessary to get the opinions of a number of observers, and also to look at colour charts; for the more utilitarian objects in the household it was possible in this way to get a more generalised opinion as to which source was to be preferred. It was only at that point that one could begin to apply the colorimetric techniques so ably described by the lecturer and thus to get a number or a series of numbers to describe what was being obtained. One of the difficulties was that while two or three figures, which one could readily grasp, might fully assess the colour appearance, the most simple system yet devised for colour rendering properties had eight spectral bands yielding eight figures which bore some relation to the colour rendering effect. An investigator found it very difficult—even with considerable experience in using them—to say just what these figures meant. That was a very real difficulty, and he asked if the author had any solution which would advance the subject in that respect.

With reference to the author's block diagram comparing daylight with the daylight fluorescent lamp, the validity of the representation depended on the choice of ordinates and abscissae. Dr. Aldington said that by using a tube with a heavy coating of magnesium tungstate in association with tungsten filament lamps a very close approximation to daylight can be produced suitable for colour matching purposes. Combinations of this sort had received considerable study in the laboratories with which he was associated.

Finally, he said that observations made in the laboratories of his company a long time ago indicated that the colour appearance of certain objects seemed to change according to whether the source of light was diffused or concentrated. He thought this might be due to a change in the proportion of light undergoing selective reflection by the coloured material and the proportion which was reflected unchanged due to the sheen of the surface.

Mr. H. R. RUFF, referring to the centre of gravity principle for mixing colours, said the author had not described how they could be put on a plain diagram. Surely, it was necessary to deal with this in the same way that simple centre of gravity problems were dealt with.

Secondly, he asked if the author could explain clearly the reason for the reflection from a pigment, and particularly a blue pigment. That was of considerable interest in connection with fluorescent lighting powders.

Thirdly, as regards adaptation, he said the only practical effect he knew, of non-adaptation to the generally used white light sources was in a sodium lighted roadway where the side lamps of motor cars always appeared to be abnormally bright.

Continuing, he said that the author had shown a diagram with knobs on, but the difficulty was to assess what the knobs really meant. It was this difficulty which had led eventually to the selection of eight bands for the spectral measurement of the mercury vapour lamp.

Finally, he referred to the interference of the spectral lines with the colour

rendering characteristics and said he thought the author might be agreeably surprised at how close colour matching could be when using fluorescent lamps with a colour temperature of about 6,500° K. In practice it had not been found possible to use this sort of lighting because people preferred what were termed warmer light sources for internal illumination.

Dr. WRIGHT, in reply, agreed with Mr. Winch that a great deal more could have been written on colour in illuminating engineering, but he had had to confine himself to one "lectures-worth," and had endeavoured to deal with the particular aspects which he had been asked to cover. With regard to the possible confusion between the ten "10 per cent." bands and the eight bands associated with the fluorescent lamp, he supposed such confusion might occur, but little could be done about it. The eight-band system certainly would not have served the purpose he had in mind, since they did not represent bands of equal luminosity. It was not clear whether these eight bands had been chosen on any sound colorimetric principle, or whether, as he had rather assumed, they were intended to cover up the spiky nature of the spectral energy curve of the fluorescent lamp.

He agreed very definitely with Mr. Winch about the importance of texture—a whole lecture could be devoted to that subject alone.

So far as the use of the terms "warm" and "cold" to describe yellowish and bluish lights was concerned, he thought this arose directly from the association of yellow, orange and red colours with the warmth of fires, etc., and blue with the coldness of the north sky, night-time, etc.

Both Mr. Winch and Dr. Aldington had referred to the research work on colour that had been carried out in their laboratories, and the author would not wish to deprecate the importance of their investigations. At the same time, he thought it was broadly true that most of the fundamental work on vision, such as colour adaptation, flicker sensitivity, colour and brightness discrimination, glare, etc., had been carried out in academic rather than industrial laboratories.

Mr. Allen's hop problem was intriguing, but difficult to analyse without seeing the installation. One could understand a dark surround being preferable to a light surround, but on the accepted principles of optimum discrimination, it would appear that grey benches would have been better than black. Perhaps these had never been tried!

Mr. Holmes had raised a big problem on the subject of the colour of light for inspection purposes. While it was true that the illuminant should possess plenty of energy in the spectral region where maximum absorption occurred in the object under inspection, nevertheless the light could not be concentrated into too narrow a spectral band, otherwise no colour differences would be revealed. What was probably needed was an illuminant with all regions of the spectrum well represented, hence the inspection of blue materials could hardly be carried out in too yellow a light. After all, the bluish-white light used for inspecting yellow surfaces contained a good deal of energy at the long-wave end of the spectrum.

It would take too long to give an adequate answer to the other questions of colour contrast raised by Mr. Holmes, but it would seem to the author that in many problems no one colour contrast was likely to be strikingly superior to many other colour combinations. Further, the appearance alone might not be the only factor in determining the choice of a colour contrast, chromatic aberration, after-images, speed of response, being examples of other factors that might have to be considered.

The author found it difficult to account with certainty for the apparent

preference for yellowish light, but was doubtful whether it could be attributed to adaptation. It seemed more likely to be due to the association of yellowness with warmth, as mentioned earlier.

Continuing, Dr. Wright said he had not advocated the exclusive use of the trichromatic equation for the specification of the colour of fluorescent lamps, as suggested by Dr. Strange, and he recognised that the residual colour—or dominant wavelength method, as it was more usually described—had certain advantages. After all, this was accepted as a legitimate alternative type of specification on the C.I.E. system. The chief difficulty was the selection of a suitable reference white, which would have to be chosen to be as nearly subjectively neutral in colour as possible. Another job for the research laboratories!

In reply to Mr. Long, Dr. Wright pointed out that the ten spectral bands he had described had been calculated for the standard C.I.E. "S_c" illuminant (colour temperature 6,500°K) and not for a fluorescent lamp. There was no difficulty in calculating the bands for other colour temperatures or for the fluorescent lamp, provided the energy distribution of the latter was known.

The author was not sure that his own experience confirmed Mr. Lay's remarks, but it was very difficult to give any valid explanation without more detailed information about the actual yellow and blue colours involved, their areas, their brightness, and so on.

Another big problem had been raised by Dr. Aldington in connection with the appearance of colours. The position of a colour on the chromaticity chart, which could be calculated from the quality of the illuminant and the reflection curve of the surface, gave some guide, but the appearance was, of course, affected by contrast, adaptation, size, etc. Fundamentally, it seemed wrong to expect to be able to specify appearance quantitatively—one could only look at an object under given conditions of observation and make a mental note of its appearance, as had been done by Dr. Aldington. No doubt, however, experiments of this sort could be systematised to some extent to make the results more generally applicable.

He was very interested in Dr. Aldington's remarks about diffuse and directional illumination. There could be no doubt that with some types of surface a change in the character of the lighting could produce a considerable colour change.

He did not quite understand Mr. Ruff's difficulty about the "centre of gravity" principle for colour mixture calculations. As the author had explained in his "Measurement of Colour," all that was necessary was a knowledge of the number of trichromatic units of each radiation in the mixture. These units corresponded to the weights in the centre of gravity problem.

With regard to the reflection of light from a pigment, this occurred through the multiple reflections within the individual pigment particles. The coloration occurred by the selective absorption of light in its passage through the particles. The author was not aware that blue pigments differed essentially in the manner of light reflection in comparison with other colours.

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With a view to avoiding possible confusion with other publications, reference to these Transactions should be in the form :—"Trans. Illum. Eng. Soc. (London)."

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Maddison Wm. .....Macclesfield Corporation Electricity Dept., Electric House, Macclesfield, CHESHIRE.
Matthews, S. A. ...32, Scotsdale Road, Lee, LONDON, S.E.12.
Morton, K. T. .....104, Nasmyth Street, Denton, LANCS.
Mott, N. S. .....9, Howard Street, GLOUCESTER.
Neale, E. U. .....21, Victoria Road, BEDFORD.
Patterson, W. .....4, Midlothian Drive, Blundellsands, LIVERPOOL, 23.
Roper, E. W. .....96, Basford Park Road, Newcastle-under-Lyme, STAFFS.
Rose, E. W. .....26, Sunnyside, Princes Park, LIVERPOOL, 8.
Rourke, T. K. .....44, Bethwin Road, Camberwell, LONDON, S.E.5.

(Continued on page 22)

SESSION 1946-1947

Present Officers and Members of Council :—

President *:—Mr. J. S. DOW, B.Sc., A.C.G.I., F.I.E.S.*

Past Presidents *:—*

Mr. A. P. TROTTER, M.INST.C.E., F.I.E.S.
Sir JOHN HERBERT PARSONS, C.B.E., F.R.S., F.I.E.S.
Sir CLIFFORD PATERSON, D.SC., O.B.E., F.R.S., F.I.E.S.
Dr. J. W. T. WALSH, M.A., M.I.E.E., F.I.E.S.
The Rt. Hon. the EARL OF MOUNT EDGCUMBE, T.D., M.INST.C.E., M.I.E.E., F.I.E.S.
Lt.-Com. HAYDN T. HARRISON, M.I.E.E., R.N.V.R., F.I.E.S.
Mr. C. W. SULLY.
Mr. H. HEPWORTH THOMPSON.
Mr. A. W. BEUTTELL, M.I.E.E., F.I.E.S.
Mr. A. CUNNINGTON, B.SC., M.I.E.E., F.I.E.S.
Dr. S. ENGLISH, M.I.E.E., F.INST.P., F.I.E.S.
Mr. PERCY GOOD, M.I.E.E., F.C.G.I., F.I.E.S.
Mr. F. C. SMITH, M.INST.GAS E., F.I.E.S.
PROFESSOR J. T. MACGREGOR-MORRIS, D.SC., M.I.E.E., F.I.E.S.
Mr. W. J. JONES, M.SC., M.I.E.E., F.I.E.S.
Mr. R. O. ACKERLEY, F.I.E.S.
Dr. H. BUCKLEY, F.INST.P., F.I.E.S.
Mr. E. STROUD, F.I.E.S.
Mr. H. C. WESTON, F.I.E.S.

Vice-Presidents *:—*

Mr. J. M. Waldram, B.Sc., A.C.G.I., F.I.E.S.
Mr. N. V. Everton
Mr. J. S. Preston, M.A., F.Inst.P., F.I.E.S.

Members of Council :—

Dr. J. N. ALDINGTON (1945)
Mr. C. J. ALLDERIDGE (1946)
Mr. M. G. Bennett (1945)*
Mr. P. V. Burnett (1944)
Mr. W. J. G. Davey (1944)
Mr. L. J. DAVIES (1946)
Mr. C. E. GREENSLADE (1946)
Dr. W. M. HAMPTON (1945)
Mr. A. G. HIGGINS (1945)
Prof. T. David JONES (1946)
Mr. T. S. JONES (1946)
Mr. R. Maxted (1944)
Mr. E. W. MURRAY (1946)
Mr. A. J. PASHLER (1946)
Mr. A. G. PENNY (1946)
Mr. C. W. M. Phillips (1944)
Mr. E. B. SAWYER (1945)
Mr. Geo. Smith (1944)
Mr. W. R. STEVENS (1946)
Dr. W. S. STILES (1945)
Mr. F. WALKER (1946)
Dr E. C. Walton (1946)
Mr. G. T. Winch (1944)
Dr. W. D. WRIGHT (1945)

* Retirement at own request.

Representatives of Areas *:— (ex-officio)*

Midland—	Mr. J. G. EVERETT
North Eastern—	Mr. R. W. GREGORY
North Midland—	Mr. H. W. HARRIS
North Western—	Mr. L. G. HARRIS
Scottish—	Mr. J. M. HENSHAW
South Wales—	Mr. S. G. TURNER
Western—	Mr. L. C. RETTIG

Hon. Treasurer *:—*
Mr. Percy Good (1946)

Hon. Secretary *:—*
Mr. H. C. Weston (1946)

Hon. Editor of Transactions *:—*
Dr. S. English (1946)

The names in italics are those of Officers or Members retiring in 1947. The date in parentheses after each name indicates the date of election to Office or Membership of the Council.

ELECTION OF OFFICERS AND COUNCIL

SESSION 1947-1948. OFFICIAL NOTICE

IN accordance with the procedure specified in the Articles of the Society, a list of existing Officers and Members of Council, of vacancies occurring and of duly qualified persons nominated by the Council for vacancies about to occur in the offices of President, Vice-Presidents, Hon. Treasurer, Hon. Secretary, and Ordinary Members of Council, is presented below for the information of the Members of the Society.

In the event of any Members desiring to put forward other names, the Council will be pleased to receive such nominations, which should be made in accordance with the following rule (Article 48):—

> "After the issue of the Council's list, and not later than the 15*th day of April* next following, any ten Members (but no more than ten) may nominate any other duly qualified person to fill any such vacancy by delivering such nomination in writing to the Hon. Secretary, together with the written consent of such person to accept office if elected, but each such nominator shall be debarred from nominating any other person for the same office at such election."

Nominated by the Council to fill Vacancies:—

***President*:—**

Dr. J. W. T. WALSH, M.A., M.I.E.E., F.I.E.S.

***Vice-Presidents*:—**

Mr. J. M. WALDRAM, B.SC., A.C.G.I., F.I.E.S.
Mr. J. S. PRESTON, M.A., F.INST.P., F.I.E.S.
Dr. E. C. WALTON, B.ENG., A.M.I.E.E.

***Members of Council*:—**

Mr. C. R. BICKNELL
Mr. HAROLD BRIGHT
Mr. S. D. LAY
Mr. H. A. LINGARD
Dr. J. H. NELSON
Mr. J. S. SMYTH
Mr. J. F. STANLEY
Mr. P. CRAWFORD SUGG

***Representatives of Centres*:—**
(ex-officio)

To be appointed before October 1, 1947.

***Hon. Treasurer*:—**
Mr. J. G. HOLMES

***Hon. Secretary*:—**
Mr. H. C. WESTON

***Hon. Editor of Transactions*:—**
Dr. S. ENGLISH

Sessional Meeting in London

A Sessional Meeting was held at the E.L.M.A. Lighting Service Bureau, 2, Savoy-hill, London, W.C.2, at 6 p.m. on Tuesday, January 14, 1947.

Mr. J. S. Dow (President) was in the chair.

The minutes of the last meeting having been taken as read and confirmed, the President called upon Dr. W. D. Wright to deliver his paper, entitled "Colour in Illuminating Engineering."

The paper reviewed some of the problems of colour perception as they affected the illuminating engineer. Colour matching by a mixture of three matching stimuli was described, together with the development of the C.I.E. system of colour specification. Reference was also made to colour charts based on the Munsell and Ostwald systems.

After a vote of thanks, proposed by the President, had been carried, a discussion was opened by Mr. G. T. Winch, who was followed by Dr. J. H. Nelson, Mr. W. A. Allen, Mr. J. G. Holmes, Dr. J. W. Strange, Mr. J. M. Waldram, Mr. Howard Long, Mr. S. D. Lay, Dr. J. N. Aldington, and Mr. H. R. Ruff. After Dr. Wright had replied to the discussion the meeting was terminated.

Additions to List of Members

(Continued from page 19)

CORPORATE MEMBERS:—

Rowe, B. V. .....43, Scraptoft Lane, LEICESTER.
Scholey, E. G. .....15, Bell Hall Mount, Savile Park, HALIFAX.
Shannon, J. M. .....72a, Waterloo Street, GLASGOW.
Sharpley, F. W. .....c/o Nuffield Laboratory of Ophthalmology, Walton Street, OXFORD.
Spittle, G. .....50, Benton Road, Heaton, NEWCASTLE-ON-TYNE, 7.
Stephens, G. .....61, Belgrave Gate, LEICESTER.
Stern, W. L. .....207, Anerley Road, LONDON, S.E.20.
Tuckett, C. H. .....15, Mayfield Road, Timperley, CHESHIRE.
Veitch, C. C. .....61, Carr Lane, Willerby, E. YORKS.
Warren, D. J. .....111, Monkhams Lane, Woodford Green, ESSEX.
Watts, F. H. ....."Berriville," Arle Drive, Cheltenham, GLOS.
Wescoe, W. S. .....20, Cross Bentley Lane, LEEDS, 6.
Whittiker, L. W. .....33, Essex Road, Acton, LONDON, W.3.
Williams, H. .....7, Cockshutt Drive, SHEFFIELD, 8.

STUDENT MEMBERS:—

Chapman, D. F. .....24, Ashville View, Cardigan Road, LEEDS, 6.
Wallwork, R. .....18, Leigh Avenue, Swinton, LANCS.

TRANSFERS TO CORPORATE MEMBERSHIP:—

Chapman, N. C. .....31, Roslin Way, Bromley, KENT.
Oxford, C. G. H. ..."Dudley," Brownsea View Avenue, Parkstone, DORSET.
Pears, G. E. .....57, Friars Place Lane, Acton, LONDON, W.3.
Pearson, J. ....."Dalegarth," Rein Road, West Ardsley, Wakefield, YORKS.

I.E.S. Fellowship.

The following applications for Fellowship have been accepted:—

Tew, A. Sugg, P. Crawford.

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